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The Intriguing Plerionic Supernova Remnant: G21.5-0.9

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Abstract. G21.5−0.9 is a center-brightened (or plerionic) supernova remnant (SNR) whose properties hint at the presence of a pulsar – yet no pulsations have been found at any wavelength. Early observations with *Chandra* led to the discovery of an extended component, making the SNR at least twice as big as originally thought. Our analysis indicates that this low-surface brightness extended component is non-thermal with a filamentary hard structure in the northern quadrant. We perform a spatially resolved spectroscopy and find no evidence of line emission using a 72 ksec exposure with ACIS-S. The $5'$ diameter remnant is well fitted with a power law with a photon index steepening from 1.5 to 2.7 (N_H=2.2×10^{22} cm^{-2}). Using a 76 ksec exposure with the HRC, we derive an upper limit of 16% on the pulsed fraction from a putative pulsar. We also infer the parameters of the 'hidden pulsar' in G21.5−0.9. This remnant remains unique and intriguing since it is, to date, the only candidate whose size is bigger in X-rays than in the radio.

1. Introduction

G21.5−0.9 has a flat radio spectral index, and is highly polarized (Green 2000). It is a $1.3'$ diameter plerion ($\sim$ 1.9 pc at a distance of 5.0 kpc) in the radio, infrared, and in X-rays (prior to *Chandra*; Becker and Szymkowiak 1981). Early *Chandra* observations (Slane et al. 2000) revealed a low-surface brightness extended component interpreted as the missing SNR shell. G21.5−0.9 shares similar properties to 3C 58 and CTB 87, plerions having a spectral break at low frequencies and classified as plerions of the *second kind* (Woltjer et al. 1997). Bock, Wright, & Dickel (2001) have however recently questioned the spectral break in G21.5−0.9. In this paper, we highlight the *Chandra* observations.

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More details about the analysis (including *ROSAT* and *ASCA* observations) and interpretation of our results can be found in Safi-Harb et al. (2001).

2. Imaging

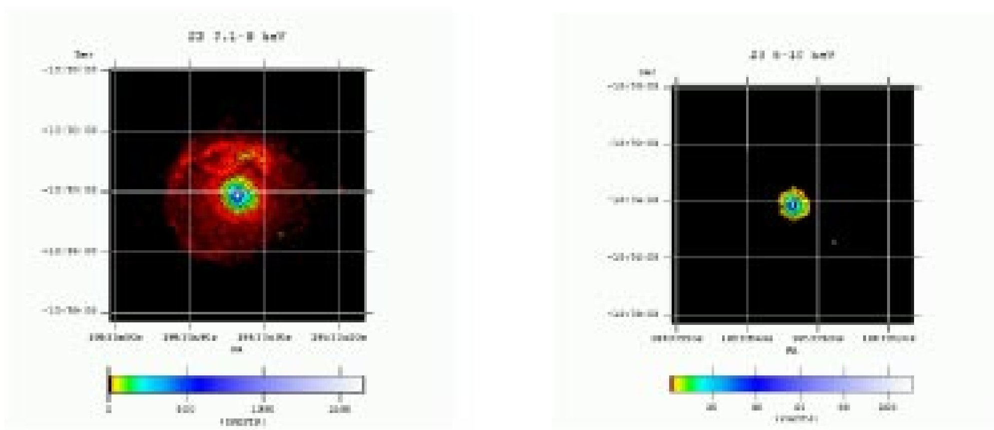

Figure 1. Soft (Left) and hard (Right) energy images of G21.5-0.9. The extended component is evident in the soft band image.

In Fig. 1, we show the *Chandra* images of G21.5−0.9 in the soft and hard energy bands. With *ROSAT* and previous radio observations, only the bright $40''$ radius core is detected. *Chandra* allowed the discovery of a faint extended component (Fig. 1, left) making the SNR at least twice as big as previously thought. In Fig. 2, the hardness ratio map (2.4–10 keV over 0.5–2.4 keV) shows that the central core is harder than the extended component (in agreement with our spectral analysis below). Moreover, the extended component is harder in the northern quadrant, with brighter knots and filamentary structures.

3. Spatially Resolved Spectroscopy:

We perform a spatially resolved spectroscopy of the plerion using a 72 ksec exposure with *Chandra* ACIS S3. The spectrum of the inner core is extracted from a circle of radius R=$40''$ (with rings of 5" thickness). For the extended component, we extract a spectrum from $50''$–$150''$. All spectra are best described by a power law with the photon index, Γ, steepening away from the bright center from 1.5 to 2.7 (N_H=2.2×10^{22} cm^{-2}). We rule out thermal models for the extended component. Collisional equilibrium ionization (CEI) models, such as *apec*, yield poor fits ($\chi^2_\nu\sim1.15$). Non-equilibrium ionization (NEI) models, such as *PHSOCK*, are unlikely since they yield a very low ionization timescale, and an interstellar column density, N_H, much lower than that derived for the SNR (Table 1). Furthermore, we find no evidence of line emission from the filaments and knots. Their spectra are well fitted with a power law model.

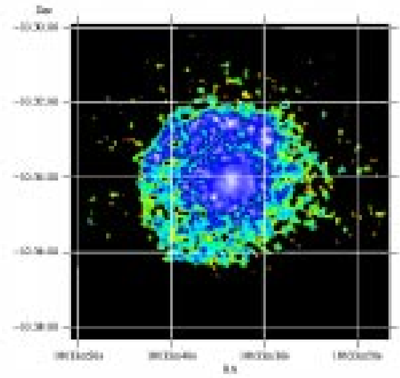

Figure 2. Hardness ratio map (2.4–10 over 0.5-2.4 keV) obtained with ACIS-S and smoothed with a Gaussian with σ=3". The northern knotty quadrant is harder than the rest of the extended component.

Table 1. Spectral parameters of the fits to the low-surface-brightness extended component using ACIS-S3 observations.

Model	$N_H{}^a(\times 10^{22}$ cm$^{-2})$	Model Parameter	χ^2_ν (ν)
Power Law	1.83 (1.77–1.90)	Γ = 2.36 (2.30-2.43)	1.0 (658)
PSHOCK	1.53 (1.48–1.57)	kT = 3.50 (3.28–3.74) keV	0.86 (657)
		τ^b= 1.1 (0.8–1.3)$\times 10^9$ cm^{-3} s	

[a]Best fit values are indicated. When freezing N_H to 2.2 $\times$ 10^{22} cm^{-2}, the power law model gives Γ = 2.73 $\pm$ 0.04 (χ^2_ν = 0.98; ν = 659), and thermal models are rejected ($\chi^2_\nu\sim$1.5)

[b]The ionization timescale, $n_e t$; where n_e is the postshock electron density, and t is the age of the shock

4. The putative pulsar

The morphology and spectrum of the inner core indicate the presence of a pulsar powering G21.5−0.9. We did not find pulsations using the *ASCA* and *Chandra* archival observations. Using 5 HRC observations totaling to 76 ksec, we put an upper limit on the pulsed fraction of 16%. We also measure an unabsorbed flux of 2.4×10^{-12} erg cm^{-2} s^{-1} from the point source. The failure to detect pulsations could be due to a beaming effect. Using various L_X–$\dot{E}$ empirical relationships for pulsar-powered plerions, we find that a plausible estimate of the spin down energy loss, $\dot{E}$, is $\dot{E}_{37} \equiv \dot{E}/(10^{37}$ erg s$^{-1}) \sim$ 3–6. In the Kennel and Coroniti (1984) model, the pulsar wind gets shocked at a radius, R_s, given by equating the pressure of the pulsar's wind with the pressure in the nebula. Beyond this radius, a non-relativistic flow transports the plasma from the shock region to the edge of the nebula. The size of the nebula, R_n is related to the shock radius, R_s as: $R_n/R_s \sim 1/\sqrt{\sigma}$; where σ is the so-called pulsar wind magnetization parameter defined as the ratio of the Poynting flux to the particles flux . Using the power law fit to the inner 40″ radius core, we estimate a shock radius R_s $\sim$ 0.08–0.11 pc ($\sim$ 3″–5″ at 5 kpc). The pulsar wind parameter σ is $\sim$ (4–11) $\times$ 10^{-4}, indicating a particle dominated wind. In Table 3, we summarize the inferred parameters of the putative pulsar in G21.5−0.9, in comparison with the Crab and 3C 58 pulsars.

Table 2. Inferred parameters of the putative pulsar in G21.5-0.9, in comparison with the Crab and the newly discovered pulsar in 3C 58 (Slane et al., this proceedings).

	G21.5−0.9	Crab	3C 58
Distance (kpc)	5	2	2.6
L_X (0.5–10 keV) (10^{35} erg s^{-1})	$3.3D_5^2$	210	0.3
$\dot{E}$ (10^{37} erg s^{-1})	3–6	47	2.6
σ	(4–11)$\times10^{-4}$	3×10^{-3}	–
P (ms)[a]	$144\tau_3^{-0.5}\dot{E}_{37}^{-0.5}$	33	67
B_0 (10^{13} Gauss)	$1.1\ \tau_3^{-1}\dot{E}_{37}^{-0.5}$	0.4	0.36

[a] τ_3 is the age in units of 3 kyr; $\dot{E}_{37}$ the spin-down energy loss in units of 10^{37} erg s^{-1}

5. Conclusions and future work

The extended component is non-thermal–in agreement with *XMM-Newton* observations (Warwick et al. 2001). The softening of the spectral index away from the core could be explained by synchrotron losses. Unlike other plerions, G21.5−0.9 is the only candidate whose X-ray size is bigger than its radio size. Deep radio observations (recently performed with the VLA) will allow us to search for the radio counterpart of the extended X-ray component and the missing SNR shell. Since G21.5−0.9 is bright and heavily absorbed, a significant fraction of its flux would be scattered by dust (R. Smith, private communication). Future work should include modeling a dust scattering X-ray halo.

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